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Tea, Kombucha, and health: a review

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Abstract

Kombucha is a refreshing beverage obtained by the fermentation of sugared tea with a symbiotic culture of acetic bacteria and fungi, consumed for its beneficial effects on human health. Research conducted in Russia at the beginning of the century and testimony indicate that Kombucha can improve resistance against cancer, prevent cardiovascular diseases, promote digestive functions, stimulate the immune system, reduce inflammatory problems, and can have many other benefits. In this paper, we report on studies that shed more light on the properties of some constituents of Kombucha. The intensive research about the effects of tea on health provide a good starting point and are summarized to get a better understanding of the complex mechanisms that could be implicated in the physiological activity of both beverages.

Keywords: Tea; Kombucha; Health; Chemical composition; Beneficial property; Adverse reactions; Review

1. Introduction

A large amount of information has been published concerning the effects of tea and its major constituents on human health. This beverage has been consumed in many countries for a very long time, and today interest is growing because scientific reports indicate that tea could bring benefits for health and may help prevent chronic diseases. Tea was first introduced into European countries from China by Portuguese and Dutch explorers as a medicinal herb (Hollman, Hertog & Katan, 1996). Over the years, tea consumption became associated with eating and living habits just like coffee or soft drinks without regards to its benefits. The aging of the population and limitations of modern medicine have caused many people to look for new ways to improve their health. Doubts surrounding lifestyle and diet along with the growing interest in functional foods and nutraceuticals have contributed to this trend.

When we study the development of civilization and the role of food and folk medicine, we often discover that many foods and beverages were used for their assumed beneficial effects on health. Tea is the oldest known medicine. It was taken in China 5000 years ago for its stimulating and detoxifying properties in the elimination of alcohol and toxins, to improve blood and urine flow, to relieve joint pains, and to improve resistance to diseases (Balentine, Wiseman & Bouwens, 1997). Tea grew rapidly in importance and was incorporated into many social rituals notably in China, Japan and England. Today, tea is the second most popular beverage in the world after water (Yang & Wang, 1993).

Another beverage known as Kombucha, is produced by the fermentation of tea and sugar by a symbiotic association of bacteria and yeasts forming a ''tea fungus''. It also originated in China where the ''Divine Che'' was prized 220 BC during the Tsin Dynasty for its detoxifying and energizing properties (Roche, 1998). In 414, Doctor Kombu brought the tea fungus to Japan from Korea to cure the digestive troubles of the Emperor. ''Tea Kvass'' was introduced into Russia by oriental merchants and then into Eastern Europe and Europe around the turn of this century. This refreshing beverage tasting like sparkling apple cider is often produced in the home by fermentation using a tea fungus passed from home to home.

The composition and properties of tea are well documented, but scarce scientific information is available concerning the composition and the effects of Kombucha

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on health. Benefits have been reported by testimony of users in different conditions and with variable consummation. The purpose of this review is to point out the biological activity of both beverages, the specific substances implicated in the biological activity, and to try to establish a better understanding of Kombucha and its possible health benefits. A thorough knowledge of tea, its composition and effects on metabolism and health provides a starting point to understanding the potential of Kombucha.

2. From tea to Kombucha: the fermentation process

Tea plants belong to the *Theaceae* family and come from two main varieties: *Camellia sinensis* var. *sinensis* and *Camellia sinensis* var. *assamica* (Hara, Luo, Wickremashinghe & Yamanishi, 1995a). The first apical leaves are picked from the evergreen shrub and can be processed by different methods. Green tea is readily dried with or without a fixation step to inactivate enzymes (Hara, Luo, Wickremashinghe & Yamanishi, 1995b). Black tea, the most popular form around the world, is the result of the oxidation of leaf polyphenols through a multi-stage enzymatic process (Hara, Luo, Wickremashinghe & Yamanishi, 1995d). New polyphenol molecule complexes are formed during the processing of black tea (Fig. 1)

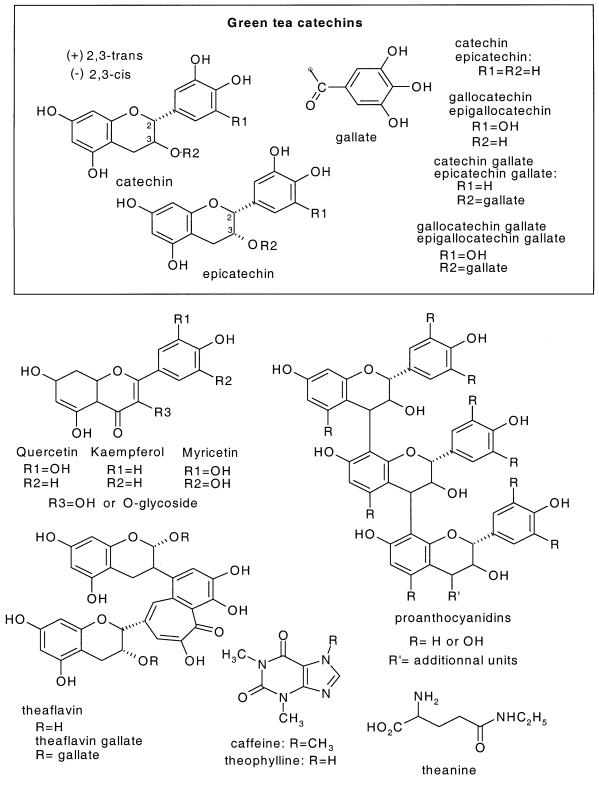

Fig. 1. Chemical structure of some tea constituents.

Black tea and white sugar are the best substrates for the preparation of Kombucha, although green tea can be used also (Reiss, 1994). Tea leaves are added to boiling water and allowed to infuse for about 10 min after which the leaves are removed. Sucrose (50 g/l) is dissolved in the hot tea and the preparation is left to cool. Tea is poured into a wide-mouthed clean vessel and is acidified by the addition of vinegar or already prepared Kombucha. The tea fungus is laid on the tea surface, and the jar is carefully covered with a clean cloth and fastened properly. The preparation is allowed to incubate at room temperature (between 20° and 30°C) for 1–8 weeks. During fermentation, a daughter tea fungus is formed at the tea surface. The tea fungus is removed from the surface and kept in a small volume of fermented tea. The beverage is passed through cheesecloth and stored in capped bottles at 4°C. The taste of the Kombucha changes during fermentation from a pleasant fruit sour-like lightly sparkling flavour after a few days, to a mild vinegar-like taste with prolonged incubation (Blanc, 1996; Reiss, 1994; Sievers, Lanini, Weber, Schuler-Schmid & Teuber, 1995).

The microbiological composition of the tea fungus has been investigated. Bacteria and fungus present in Kombucha form a powerful symbiosis able to inhibit the growth of potential contaminating bacteria (Balentine, 1997; Liu, Hsu, Lee & Liao, 1996). The main acetic acid bacteria found in the tea fungus are: *Acetobacter xylinum* (Balentine, 1997), *A. xylinoides*, *Bacterium gluconicum* (Reiss, 1994), *A. aceti*, *A. pasteurianus* (Liu et al., 1996). Yeasts identified as *Schizosaccharomyces pombe*, *Saccharomycodes ludwigii*, *Kloeckera apiculata*, *Saccharomyces cerevisiae*, *Zygosaccharomyces bailii*, *Brettanomyces bruxellensis*, *B. lambicus, B. custersii*, *Candida* and *Pichia* species (Balentine, 1997; Liu et al., 1996; Mayser, Fromme, Leitzmann & Gründer, 1995) have been isolated from tea fungus. Aspects of the close association between micro-organisms that make up the fungus and their interaction with the substrates supporting fermentation have been studied (Balentine, 1997; Sievers et al., 1995; Yurkevich & Kutyshenko, 1998). *Acetobacter xylinum* has the ability to synthesize a floating cellulose network which enhances the association formed between bacteria and fungi (Balentine et al., 1997). The yeast cells convert sucrose into fructose and glucose and produce ethanol (Reiss, 1994; Sievers et al., 1995). Acetic acid bacteria convert glucose to gluconic acid and fructose into acetic acid. Caffeine and related xanthines of the tea infusion stimulate the cellulose synthesis by the bacteria, (Balentine et al., 1997). Acetic acid stimulates the yeast to produce ethanol and ethanol in turn can be helpful to acetic acid bacteria to grow and produce acetic acid (Liu et al., 1996). Both ethanol and acetic acid have been reported to have antimicrobial activity against pathogenic bacteria thereby providing protection against contamination of the tea fungus (Liu et al., 1996).

3. Tea and its biological activity

3.1. Chemical composition

The chemical composition of tea leaves has been thoroughly studied. The main constituents of green tea leaves belong to the polyphenol group accounting for 25–35% on a dry weight basis (Balentine et al., 1997; Hara, Luo, Wickremashinghe & Yamanishi, 1995c). Important and characteristic tea polyphenols are the flavanols of which catechins (flavan-3-ols) are predominant and the major ones are: ( )-epicatechin (EC), ( )-epicatechin gallate (ECG), ( )-epigallocatechin (EGC), ( )-epigallocatechin gallate (EGCG), (+)-catechin (C), and (+)-gallocatechin (GC) (Hara et al., 1995c) (Fig. 1). These compounds contribute to the bitterness, astringency and sweet aftertaste of tea beverages (Hara, Luo, Wickremashinghe & Yamanishi, 1995e). Tea contains also flavonols, mainly quercetin, kaempferol, myricetin, and their glycosides (Fig. 1). In black tea, the oxidation of polyphenols during processing leads to the formation of catechins and gallic acid complexes such as theaflavins, theaflavinic acids, thearubigins or theasinensis, and of proanthocyanidin polymers (Balentine et al., 1997; Hara et al., 1995d). (Fig. 1) Methylxantines are present with 2–4% as caffeine and a small amount of theophylline and of theobromine (Hara et al., 1995c). (Fig. 1). Tea contains many amino acids, but theanine, specific to the tea plant, is the most abundant, accounting for 50% of the total amino acids, (Fig. 1). Amino acid degradation is involved in the biogenesis of the tea aroma (Balentine et al., 1997). Chlorophyll, carotenoids, lipids, and volatile compounds are not major constituents in a tea brew but they also play an important role in the development of the aroma (Hara et al., 1995c). Volatile fractions of tea leaves have been studied in detail and more than 600 different molecules have been isolated (Hara et al., 1995c,e; Shimoda, Shiratsuchi & Osajima, 1995; Shimoda, Shigematsu, Shiratsuchi & Osajima, 1995). These include terpenoids and degradation products of amino acids, carotenoids and linoleic acid (Hara et al., 1995c). Tea also contains carbohydrates, vitamins E, K, A, low levels of B vitamins and vitamin C (in green tea only). Tea also provides useful amounts of potassium, manganese and fluoride ions to the diet (Hara, Luo, Wickremashinghe & Yamanishi, 1995f). This brief overview of the complex composition of tea leaves helps to understand the constituents of tea in particular those that may promote health.

3.2. Biological activity

The scientific community has recently turned its attention to the allegation that tea is good for health. Several epidemiological studies, experimentation with animals, and in vitro studies lead to the conclusion that tea has potentially protective effects for a wide variety of health conditions. However, the evidence is not always clear cut.

3.2.1. Epidemiologic studies

Epidemiologic studies have investigated the role of green tea (Bushman, 1998; Imai, Suga & Nakachi, 1997), black tea (Blot, McLaughlin & Chow, 1997) or both in cancer prevention often without conclusive results (Yang & Wang, 1993; Yokozawa, Dong, Nakagawa, Takeuchi et al., 1998). To make sense of data generated by epidemiologic studies, individual cancers must be considered. Oral and pharyngeal cancer risks tend to be lower among tea drinkers, but results are not statistically significant (Dreosti, Wargovich & Yang, 1997). Esophageal cancer occurrence increases significantly with black tea consumption in some countries when the beverage is drunk very hot but there is no association found otherwise and one study with green tea indicates potential protective effects (Katiyar & Mukhtar, 1996). Some epidemiological studies point out that tea has a protective effect against stomach cancer although other studies found opposite results (Bushman, 1998; Katiyar & Mukhtar, 1996). The most comprehensive reports showed an inverse association of green tea and this type of cancer. As for esophageal cancer, drinking very hot tea raises the risk. Most studies evaluating risks for colorectal cancer have concluded that there is no clear relationship with tea drinking habits (Bushman, 1998). However, an inverse association with increased green tea intake and adenomatous colon polyps was found, but the results were not statistically significant (Bushman, 1998). A green tea intake seems to lower risks to develop pancreatic cancer in many population studies (Bushman, 1998). Inconsistent or non-correlate results were reported concerning the impact of drinking tea on prevention of lung, breast, uterus, liver, pancreas, bladder, kidney and urinary tract cancer (Yokozawa, Dong, Nakagawa, Kashiwagi et al., 1998).

For large populations, green tea would be a very useful alternative to chemical preventive agents, because it is nontoxic and readily available (Imai et al., 1997). More accurate epidemiologic studies are needed to get more conclusive results. Taken together, the present scientific information seems to indicate that black or green tea provides some protective effect against several cancers, particularly of the digestive tract (Blot et al., 1997).

Epidemiological studies have also been conducted on tea, flavonoids and the incidence of cardiovascular diseases (Mitscher, Jung, Shankel, Dou, Steele & Pillai, 1997; Tijburg, Mattern, Folts, Wiesgerber & Katan, 1997). Case-control studies showed a non-significant reduction for myocardial infarction for high black tea

consumption drinkers. Cohort studies do not provide consistent conclusions about an association between tea drinking habits and cardiovascular diseases, (Tijburg et al., 1997). However, a long-term study indicated a significant lower risk of dying from coronary heart disease and a lower incidence of strokes when people consumed tea. Tea is a good source of flavonoids and therefore, the epidemiological studies about the effect of flavonols on the incidence of cardiovascular diseases may be useful. There was no association or an inverse association between flavonol consumption and the incidence of cardiovascular diseases (Tijburg et al., 1997). The serum lipid profiles in a human cohort study indicated a decrease in serum cholesterol but no effect on serum triglycerides or high density lipoproteins (Mitscher et al.).

Many variable or confounding factors like tobacco or alcohol consumption habits, diet, life style, lack of information about frequency of tea drinking, type of tea, infusion period, pesticides used during tea leave culture, and temperature of consumption, may contribute to the inconsistency of study results. Any beneficial effects of tea could be influenced by other causative factors and the development mechanism related to one specific cancer occurrence. Epidemiologic studies can be used to generate important information concerning human response to tea consumption but more studies are required. Experimental studies conducted in vitro and with animals bring a more accurate understanding of the metabolism and function of tea components that could be used to explain the potential health benefits of tea for humans.

3.2.2. Experimental studies

Many studies have been conducted to identify active compounds in tea and to elucidate their chemical and biological properties. Several approaches led to the same findings: catechins and flavonols of tea are good antioxidants in the presence of reactive oxygen species and free radicals in both aqueous and lipophilic conditions (Cao, Sofic & Prior, 1996; He & Shahidi, 1997; Hirayama, Takagi, Hukumoto & Katoh, 1997; Huang & Frankel, 1997; Kumamoto & Sonda, 1998; Ngang, Wolniewicz, Letourneau & Villa, 1992; Roedig-Penman & Gordon, 1997; Sawai & Sakata, 1998; Vinson, Dabbagh, Serry & Jang, 1995; Wiseman, Balentin & Frie, 1997; Yokozawa, Dong, Nakagawa, Kashiwagi et al., 1998). In fact, tea catechins are the most powerful antioxidants among the known plant phenols. In some lab tests, EGCG is 20 times more active than vitamin C, 30 times more than vitamin E and 2–4 times more than butylated hydroxyanisole (BHA) or butylated hydroxytoluene (BHT) (Vinson, Dabbagh et al., 1995). The antioxidant activity increases with the number of *o*-dihydroxy groups, although the activity also depends upon the oxidation environment. In some conditions, catechins can exibit a very high potential of protection, inhibiting lipid peroxidation in brain tissue from animals with a 200 times greater activity than alpha-tocopherol (Anon, 1997). It was also demonstrated that catechins can act in a synergy with tocopherol and organic acids (Antony & Shankaranaryana, 1997; Hara et al., 1995f). In some in vitro conditions, they can exhibit a pro-oxidant effect in the presence of Cu^{2+} or Fe^{3+} and H_2O_2, as observed with other phenolic antioxidants and vitamin C (Cao et al., 1996; Yen, Chen & Peng, 1997). However, antioxidant properties of tea constituents have to be demonstrated in living material to be relevant to human health.

3.2.3. Bioavailability

It is important to look at the bioavailability of flavonoids from tea including absorption, distribution, metabolism and elimination, to get a comprehensive understanding of the possible impact on living organisms. This subject has been reviewed and the findings can be summarized (Hollman, Tijburg & Yang, 1997). Pure flavonols are poorly absorbed, but their glycosides show moderate to rapid absorption in man, probably because an active glucose transport occurs in the small intestine. Catechins and catechin condensation products from black tea are both well absorbed in humans. Catechins are metabolized extensively but the absorption and the metabolism mechanism of larger molecules present in black tea remains unclear. Catechins pass through glucuronidation, sulfation and *O*-methylation in the liver. In the colon, bacteria cleave the ring producing valerolactones, phenylpropionic and benzoic acids. Polyphenols have a strong affinity for proteins via the various phenolic groups particularly when proteins have a high proline content such as in caseins, gelatin and salivary proteins. However, the addition of milk to tea does not affect the polyphenol concentration in plasma. Tea flavonoids have also a strong affinity for iron and form insoluble complexes which reduce the bioavailibility of non-heme iron. Absorption of ascorbic acid inhibits this complex formation. This finding has important implications mainly for those people having a vegetarian diet.

Many biological activities of tea extracts can be attributed to the antioxidant properties of the polyphenol fraction through its metabolism. Protection against cardiovascular diseases, atherosclerosis, cancer, gene mutations, bacterial growth and diabetes are growing concerns. Many studies have been reported where the protective effect of tea against these diseases has been evaluated.

3.2.4. Atherosclerosis and cardiovascular diseases

The oxidation of low density and of very low density lipoproteins (LDL and VLDL) brings about the progressive obstruction of arteries or atherosclerosis, and can lead to angina pectoris, to coronary heart disease,

or to infarction (Tijburg et al., 1997). Tea flavonoids, mainly gallocatechins, protect LDL and VLDL against oxidation by aqueous and lipophilic radicals, copper ions and macrophages (Vinson, Jang, Dabbagh, Serry & Cai, 1995; Vinson & Dabbagh, 1998; Wiseman et al., 1997; Yokozawa, Dong, Nakagawa, Kim, Hattori & Nakagawa, 1998) and against the proliferation of vascular smooth muscle cells which leads to the sclerosis of the artery (Yokozawa, Oura, Sakanaka & Kim, 1995). In studies conducted with rats, a reduction of triglycerides, total cholesterol, LDL-cholesterol (Yang & Koo, 1997) and the enhancement of superoxide dismutase (SOD) in serum and of gluthatione S-transferase (GST) and catalase in the liver were observed (Lin, Cheng, Lin, Lau, Juan & Lin, 1998). Increase of SOD, GST and catalase improve removal of the superoxide anion radical, the peroxides and other free radicals responsible for LDL oxidation (Yokozawa, Dong, Nakagawa, Kashiwagi et al., 1998). Tea catechins effectively reduce cholesterol absorption from the intestine, lowering the solubility of the cholesterol and enhancing the faecal excretion of cholesterol and total lipids. In atherosclerosis, the inflammatory process is an important component. Tea extract induces an anti-inflammatory and capillary strengthening effect (Tijburg et al., 1997). Green tea also inhibits the collagen-induced aggregation of rabbit platelets and the flavonols quercetin and myricitin are strong inhibitors of ADP- and arachidonic acid-induced aggregation of human platelets, preventing the formation of a thrombus (Tijburg et al., 1997). Tea components, mainly quercetin (Tijburg et al., 1997) and theanine (Yokogoshi, Kato, Sagesaka-Mitane, 1995), reduce blood pressure in animals and in man and thus lower the risk for the development of cardiovascular diseases. Tea catechins have been found in human plasma in concentrations sufficient to have an antioxidant activity (Nakagawa, Okuda & Miyazawa, 1997) and they can inhibit LDL oxidation (Pearson, Frankel, Aeschbach & German, 1998). More human studies are needed to validate these data.

3.2.5. Cancer and gene mutations

Documentation concerning the protective effect of tea against cancer is very extensive. Some reviews are helpful (Blot et al., 1997; Mitscher et al., 1997; Yang & Wang, 1993; Yokozawa et al., 1998). Strong evidence has come from both in vitro and in vivo studies that tea can act as a protective agent at different stages of cancer development and through different mechanisms (Mukhtar and Almad, 1999).

Cells exhibit many strategies to reduce oxygen and use the energy for metabolism. Reactive oxygen species damage molecules by reacting with cell contents via unregulated pathways. Usually this is prevented by compartimentalization by lipid membranes inside the cell and protective tools like enzymes and antioxidants (gluthathione, ascorbic acid, alpha-tocopherol, urea, carotenoids, etc.). When oxygen reacts with DNA, oncogene production can result which can lead to cancer pathology through the stages of initiation, promotion and progression (Mitscher et al., 1997). Cancer can also be the result of suppression of the immune system by the prostaglandins following persistent inflammatory episodes initiated by reactive oxygen species. Many studies have indicated that tea and its constituents mainly EGCG, are antimutagenic and anti-inflammatory by intercepting carcinogenic agents and by reducing oxidant species before they can damage DNA (Halder & Bhaduri, 1998; Katiyar & Mukhtar, 1997; Mitscher et al., 1997; Yang & Wang, 1993; Yen & Chen, 1995). Catechins also protect cell membranes against oxidation, keep reactive oxygen species in confined zones and probably block cell membrane receptors required for cancer cell growth. The initiation of carcinogenesis can be overcome by the repression of some catalytic activities and of other specific enzymes involved in cancer initiation. This is complemented by the enhancement of detoxifying enzymes by EGCG (Bushman, 1998; Katiyar & Mukhtar, 1996).

Promotion and progression of cancer pathology are retarded even at later stages by tea in a variety of cancers in a range of target organs as indicated in many studies conducted with rodents (Blot et al., 1997). Laboratory research agrees with epidemiologic studies that tea can reduce the incidence and the multiplicity of esophageal and gastrointestinal cancers (Gao, McLaughlin, Blot, Ji, Dai & Fraumeni, 1994; Weisburger, Rivenson, Reinhardt, Aliaga, Braley, Pittman & Zang, 1998; Xu, Ho, Amin, Han & Chung, 1992). At low concentration, tea polyphenols block the nitrosation reaction and the resulting mutagenicity implicated in many esophageal, gastric and other tumorigenesis (Katiyar & Mukhtar, 1996; Yang & Wang, 1993). Tea extracts show an antiproliferative effect in lung and other tumor development in mice and in fibroblast cells because they inhibit cell division in the DNA damaged cells (Landau, Wang, Ding & Yang, 1998; Lin, Juan, Chen, Liang & Lin, 1996; Sazuka, Imazawa, Shoji, Mita, Hara & Isemura, 1997; Xu, Baily, Hernaez, Taoka, Schut & Dashwood, 1996) and can induce apoptosis in both malignant and non-malignant tumors in mice skin (Conney, Lu, Lou, Xie & Huang, 1999). Inhibition of skin tumorigenesis is also observed when mice are exposed to UVB radiation. In some studies, caffeine is proposed as an active ingredient along with catechins (Chung, 1999; Huang, Xie, Wang, Ho, Lou, Wang et al., 1997; Katiyar & Mukhtar, 1996; Liu, Wang, Crist, Wang, Lou, Huang et al., 1998; Lu, Lou, Xie, Yen, Huang & Conney, 1997; Wang, Huang, Lou, Xie, Reulh, Newmark et al., 1994). Topical application or oral ingestion of green tea polyphenols by mice significantly prevents tumor initiation by carcinogens and

the conversion of benign to malignant tumors induced by free radicals (Katiyar & Mukhtar, 1996; Katiyar, Agarwal & Mukhtar, 1993; Wang, Huang, Chang, Ma, Ferraro, Reulh et al., 1992). Green tea extract can protect DNA against scission induced by gamma-ray radiation, another causative factor of mutation and carcinogenesis (Yoshioka, Akai, Yoshinaga, Hasegawa & Yoshioka, 1996). Tea can also protect liver, pancreas, prostate and mammary gland against cancer induction and carcinoma growth in rodent studies (Katiyar & Mukhtar, 1996; Rogers, Hafer, Iskander & Yang, 1998; Yang & Wang, 1993). Green tea polyphenols can inhibit liver monooxygenase activity or cytochrome P450 dependant carcinogen metabolism (Yang & Wang, 1993) and protect gap junctional intercellular communication (Katiyar & Mukhtar, 1996). The anti-invasive activity observed with tea ingestion can be related to the binding of catechins with a glycoprotein and the subsequent decreased adhesion of the malignant cells to the extracellular matrix (Yang & Wang, 1993). EGCG can inhibit tumor promotion by different mechanisms. It reduces the binding of tumor promoters, hormones, cytokine and growth factors by a sealing effect on the cell membrane in mouse skin while ECG, EGCG and EGC inhibit TNF-α release induced by tumor promoter of cancer cells in surrounding tissue in a human cancer cell line (Fujiki, Suganuma, Okube, Sueoka, Suga, Imai et al., 1999). One study suggests that EGCG can inhibit the proteolytic enzyme urokinase, essential for cancer growth, and also hinders the proliferation of metastasis (Jankun, Selman & Swiercz, 1997). But EGCG can also inhibit directly telomerase activity in cancer cells and thus block their proliferative capacity (Naasani, Seimiya & Tsuruo, 1998). Quercetin is a potential suppressor of the multi-drug resistance observed in cancer chemotherapy (Inoue, Trevanich, Tsujimoto, Miki, Miyabe, Sugiyama et al., 1996).

The action of tea constituents against cancers is demonstrated in many studies with animals, but research with humans is lacking. A recent study indicates that tea polyphenols have chemopreventive effects on oral mucosa leukoplakia patients (Li, Sun, Han & Chen, 1999).

3.2.6. Antibacterial and antiviral activity

Green tea catechins have demonstrated antibacterial activity against both Gram-positive and Gram-negative bacteria which can be harmful to humans. Tea extracts inhibit enteric pathogens such as *Staphylococcus aureus*, *S. epidermis*, *Plesiomonas shigelloides* (Toda, Okubo, Hiyoshi & Tadakatsu, 1989), *Salmonella typhi*, *S. tiphimurium*, *S. enteritidis*, *Shigella flexneri*, *S. disenteriae* and *Vibrio cholerae*, *V. parahaemolyticus* (Mitscher et al., 1997; Toda et al., 1989; Toda, Okubo, Ikigai, Suzuki, Suzuki & Shimamura, 1991), *Campylobacter jejuni* and *C. coli* (Diker et al., 1991) but are not effective against *Escherichia coli*, *Pseudomonas aeruginosa* or *Aeromonas hydrophila* (Toda et al., 1989). Black and green tea extracts can also kill *Helicobacter pylori* associated with gastric, peptic and duodenal ulcer diseases (Diker & Hascelik, 1994). However, the tea concentration used in these studies exceeded normal human consumption levels. Tea polyphenols can selectively inhibit the growth of clostridia and promote the growth of bifidobacteria in human large intestine. The bacterial balance in intestinal microflora may be important for the prevention of colon cancer (Okubo & Juneja, 1997).

Antimicrobial activity against cariogenic and periodontal bacteria have been reported. Tea polyphenols inhibit *Streptococcus mutans* (Sakanaka, Kim, Taniguchi & Yamamoto, 1989), *S. sobrinus* (Sakanaka, Sato, Kim & Yamamoto, 1990) and *Porphyromonas gingivalis*, bacteria responsible for tooth decay (Kakuda, Takihara, Sakane & Mortelmans, 1994; Sakanaka, Aizawa, Kim & Yamamoto, 1996). They hinder the synthesis of insoluble glucans by glucosyltransferases, and the sucrose-dependant bacteria cell adherence to tooth and epithelium, by reducing collagenase activity (Mitscher et al., 1997; Sakanaka et al., 1990, 1996). Nerolidol in the volatile fraction of green tea, and fluoride also present in green tea, contribute to the antibacterial action of tea extracts against *Streptococcus mutans* (Antony & Shankaranaryana, 1997). Polyphenols and sesquiterpenes of tea have a synergistic effect on the antibacterial activity and the anticariogenic properties of tea (Kakuda et al., 1994). Cariogenic bacteria release lactic acid that destroy tooth enamel, but tea can increase the acid resistance of teeth to these injuries (Gutman & Ryu, 1996). Protection against caries by tea polyphenols has been demonstrated with rats (Antony & Shankaranaryana, 1997).

Some results indicate that tea catechins are potentially antiviral and antiprotozoiac agents (Gutman & Ryu, 1996). EGCG agglutinates and inhibits influenza A and B viruses in animal cell culture (Mitscher et al., 1997). An antiviral activity has been found against HIV virus enzymes and against rotaviruses and anteroviruses in monkey cell culture when previously treated with EGCG (Mitscher et al., 1997).

3.2.7. Diabetes and renal failure

Diabetes is associated with a high blood glucose content. Green and black tea extracts can decrease significantly the blood glucose level of aged rats by reducing the glucose absorption and uptake in different ways (Zeyuan, Bingying, Xiaolin, Jinming & Yifeng, 1998). It is reported that tea polyphenolics inhibit alpha-amylase activity in saliva, reduce the intestinal amylase activity which in turn lowers the hydrolysis of starch to glucose and reduces glucose assimilation (Hara et al., 1995f). It was also found that tea reduces the glucose mucosal uptake because polysaccharides inhibit

the glucose absorption and the diphenylamine of tea promotes its metabolism (Zeyuan et al., 1998). Polyphenols can also decrease digestive enzyme activity and reduce glucose absorption (Zeyuan et al., 1998). They decrease uremic toxin levels and the methylguanidine of hemodialysis patients. (Sakanaka & Kim, 1997) Polyphenols also protect against oxidative stress associated with late complications in diabetes pathology and are useful to maintain a balance between pro- and anti-oxidants in the organism (Zeyuan et al., 1998).

Tea consumption is associated with an increase in urine volume and electrolyte elimination, notably sodium, along with a blood pressure decrease (systolic and diastolic values) in hypertensive adenine-induced rats (Yokozawa, Oura, Sakanaka, Ishigaki & Kim, 1994). Green tea catechins can suppress the progression of renal failure induced in rats or in renal cell culture, relieve the related mesangial proliferation and glomerular sclerotic lesions and reduce levels of uremic toxins in the blood (Yokozawa, Chung, Young, Li & Oura, 1996; Yokozawa, Dong, Chung, Oura & Nakagawa, 1997; Yokozawa, Dong, Nakagawa, Kashiwagi et al., 1998; Yokozawa, Dong, Nakagawa, Kim et al., 1998).

3.2.8. Other protective effects of tea

Theanine, the major amino acid in green tea, can reduce blood pressure and hypertension in rats. Theanine has an equilibrating effect on the central nervous system and suppresses the increase in activity level induced by caffeine (Hara et al., 1995f). This amino acid acts as a neurotransmitter in brain and can promote the synthesis of nerve growth factor as epinephrine does in rats (Chu, Kobayashi, Juneja & Yamamoto, 1997). Green tea extract administrated to rats 1 h before an ethanol intake promotes alcohol metabolism. The results suggest that caffeine and EGCG act together, caffeine improving the alcohol metabolism and EGCG detoxifying by its antioxidant action (Kakuda, Sakane, Takihara, Tsukamoto, Kanegae & Nagoya, 1996). Tea extracts contain the flavonols quercetin, kaempferol, and myricetin, known for their antiallergic effects: they inhibit hyaluronidase activity and histamine release (Toyoda, Tanaka, Hoshino, Akiyama, Tanimura & Saito, 1997). Green tea can impart a protective effect against environmental pollutants by the preservation of protein thiol levels and cell viability (Miyagawa, Wu, Kennedy, Nakatani, Othani, Sakanaka et al., 1997).

Tea has a beneficial protective activity on several life-sustaining systems in the human body and it is easy to conclude that drinking tea has positive effects to maintain a healthy condition and to delay action of the aging process. Studies about mechanisms underlying the beneficial properties of tea on human health are progressing (Weisburger, 1999). The impact of tea consumption on longevity is not well covered by the scientific literature.

4. Beneficial effects of Kombucha

4.1. Chemical composition

To produce Kombucha, black tea ingredients and sucrose undergo progressive modification by the action of the tea fungus. The main metabolites identified in the fermented beverage are: acetic, lactic, gluconic and glucuronic acids, ethanol and glycerol (Blanc, 1996; Liu et al., 1996). Some chemical structures of important ingredients reported in Kombucha are given in Fig. 2. The presence of usnic acid in Kombucha reported once has not been confirmed in recent studies (Blanc, 1996). Usnic acid had been previously identified in lichens and can deactivate some groups of viruses. The metabolite composition and concentration depends on the tea fungus source, sugar concentration, and the time course of fermentation. With 50 g/l sucrose, concentrations of ethanol and of lactic acid are optimal (Reiss, 1994). Yeast and bacteria in the tea fungus make use of substrates by different and complementary ways. Yeast cells hydrolyse sucrose into glucose and fructose, and produce ethanol, with a preference for fructose as a substrate (Sievers et al., 1995). Acetic bacteria utilize glucose to produce gluconic acid (Sievers et al., 1995), and ethanol to produce acetic acid (Yurkevich & Kutyshenko, 1998). The presence of lactic acid was not observed in these studies but has been reported in another. In this study, the lactic acid synthesis is attributed to the action of lactic bacteria on ethanol and acetic acid (Reiss, 1994). It is also reported that the fermentation process induces the synthesis of the B complex of vitamins and folic acid (Roche, 1998). The pH value of Kombucha decreases during the fermentation process following the increase in the organic acid content (Blanc, 1996; Riess, 1994; Sievers et al., 1995). More complex interactions probably occur but have not been elucidated. It is not known how the composition of the tea itself is affected during fermentation or how it is transformed.

4.2. Biological activity

Kombucha has been consumed in many countries for a very long time. Many benefits for health have been reported based on personal observation and testimonials (Greenwalt, Ledford & Steinkraus, 1998). However, few properties have been demonstrated by scientific and experimental studies. The drink has been studied intensively since 1852, mainly in Europe, and has been reviewed (Allen, 1998; Stadelmann, 1961). Reported effects have been extracted from reviews and surveys on the web site: "The Kombucha Center" (Ferguson & Estelle, 1998; Full Circle Press, 1998) and are listed in Table 1. First reports coming from Russia at the beginning of this century and during World War I

stated that the "Russian secret home remedy" also called "Wonderdrink" helped for headaches, gastric illnesses, and especially regulates intestinal activities often disturbed by the lifestyle in the army (Allen, 1998). Between 1925 and 1950, several medical studies conducted by doctors and physicians confirmed the traditional claims about Kombucha and reported beneficial effects such as antibiotic properties, regulation of gastric, intestinal and glandular activities, relief of joint rheumatism, gout and haemorrhoids, positive influence on the cholesterol level, arteriosclerosis, toxin excretion and blood cleansing, diabetes, nervousness, and aging problems (Allen, 1998). The methodology used in these studies remains unclear. In 1951, an important population study conducted in Russia by the "Central Oncological Research Unit" and the "Russian Academy of Sciences in Moscow" found that the daily consumption of Kombucha was correlated with an extremely high resistance to cancer. The 1960's, researches reaffirmed the cancer healing properties of Kombucha, its detoxifying effects and proposed that a long term consumption increased the immune system performance and boosted interferon production. The Russian findings about Kombucha properties were further supported in Switzerland, Germany and Netherlands (Allen, 1998). A recent study reported the antibiotic activity of Kombucha against *Helicobacter pylori*, *Esherichia coli*, *Staphylococcus aureus* and *Agrobacterium tumefaciens* mainly related to the acetic acid produced during the fermentation (Steinkraus, Shapiro, Hotchkiss & Mortlock, 1996). Tea extracts used at the same concentration did not exhibit any effect. A study on the antimicrobial activity of some organic acids indicated that acetic acid can inhibit fungal growth and presents a mild activity at low pH against lactic acid bacteria (Matsuda, Yano, Maruyama & Kumagai, 1994). In the same conditions and over a range of pH values, D and L-lactic acid inhibit lactic acid bacteria but present no activity against fungi while gluconic acid exhibits only weak activities against both types of microorganisms.

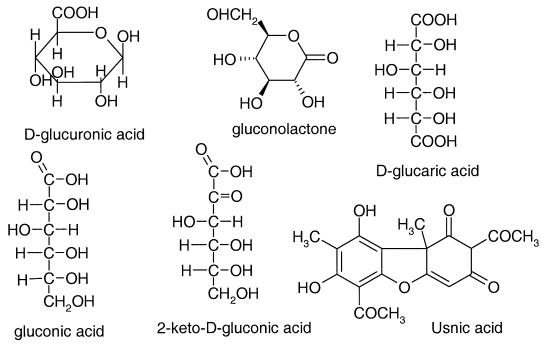

Fig. 2. Chemical structure of some Kombucha constituents.

Most properties of Kombucha are attributed to the acidic composition of the beverage. Its detoxifying property is presumably due to the capacity of glucuronic

Table 1
Reported effects of Kombucha from drinker's testimony (a: Furguson and Estelle, 1998; b: Full Circle Press, 1998) and Russian researches (c: Allen, 1998) compared to the health effects of tea demonstrated by scientific studies previously reviewed in this paper

Kombucha	Tea
Detoxify the body [a, b]	
Reduce cholesterol level [c]	x
Reduce atherosclerosis by the regeneration of cellular walls [c]	x
Reduce blood pressure [a, c]	x
Reduce inflammatory problems [c]	x
Alleviate arthritis, rheumatism and gout symptoms [a, b, c]	
Promote liver functions [c]	x
Normalize intestinal activity and balance intestinal flora, cured haemorrhoids [b, c]	
Reduce obesity and regulate the appetite [b, c]	
Prevent/heal bladder infection and reduce kidney calcification [b, c]	
Stimulate the glandular system [c]	
Protect against diabetes [c]	x
Increase the body resistance to cancer [c]	x
Have an antibiotic effect against bacteria, viruses and yeasts [a, b, c]	x[a]
Enhance the immune system and stimulate interferon production [c]	
Relieve bronchitis and asthma [a, b]	
Reduce menstrual disorders and menopausal hot flashes [a, b]	
Improve hair, skin and nail health [a, b, c]	
Reduce alcoholic's craving for alcohol [a, b]	
Reduce stress and nervous disturbances, insomnia [a, b, c]	
Help for headaches [b, c]	
Improve eyesight [a, b]	
Counteract aging problems [a, c]	
Enhance general metabolism [c]	

[a] The effects are observed at high concentrations of tea only.

acid to bind to toxin molecules and to increase their excretion from the organism by the kidneys or the intestines. Gout, rheumatism, arthritis or kidney stones likely produced by the accumulation of toxins in the body may be relieved this way. Heavy metals or environmental pollutants can also be excreted through the kidneys after glucuronidation. However, the presence of glucuronic acid in Kombucha and the formation of glucuronide complexes associated with its consumption is much debated (Hoffmann, 1998). A more recent study indicates that the substance identified in Kombucha as glucuronic acid is more likely 2-keto-gluconic acid (Roussin, 1999). High levels of glucuronides are found in the urine of Kombucha drinkers and two explanations have been proposed. The first suggests that this increase is associated to an increase in glucuronic acid intake alone and the second attributes it to the presence of a potent beta-glucuronidase inhibitor that could be saccharic acid 1,4-lactone which is also found in Kombucha (Roussin, 1999). In fact, it is not glucuronic acid that plays an important role in the detoxifying process, but UDP-glucuronic acid, the active form, found in the liver (Hoffmann, 1998). UDP-glucuronic acid is not found in Kombucha but several intermediate products of the glucuronic acid pathway have been found such as saccharic acid, ascorbic acid and saccharolactone (Hoffmann, 1998). Much more work is needed to elucidate the agents and mechanisms implicated in the detoxifying process.

The action of Kombucha intake on the nervous system could be associated with its content of the B complex of vitamins (Roche, 1998). It has been observed that patients suffering from cancer do not have L-lactic acid in their connective tissues and have a blood pH higher than 7.56. Kombucha can re-equilibrate the blood pH and the lactic acid concentration (Roche, 1998). The laxative activity of Kombucha is also attributed to its lactic acid content (Reiss, 1994). There are some indications that lactic acid bacteria can also exert immunostimulatory effects in the host (Marteau & Rambaud, 1993) but at this time, it is not known if micro-organisms present in Kombucha can colonize the human gastrointestinal system. Studies generally lack rigorous experimental investigation and mechanisms of action remain uncertain or unknown.

The tea fungus is also used for medical purposes in skin therapy. The cellulosic pellicle formed mainly by *Acetobacter xylinum* during the fermentation of tea has been used as a temporary skin substitute on burns and in other skin injuries (Fontana, Franco, De Souza, Lyra & De Souza, 1991).

5. The benefits of tea and more?

Tea and Kombucha are presented in the literature as two very distinct beverages and no correlation between them has been reported. But some effects of Kombucha intake are similar to those postulated for tea itself. The report from the Russian cancer research project among populations after World War II, associated the habit of drinking "tea kvass" to a low cancer incidence in definite areas (Roche, 1998). This observation could be linked to the anti-cancer activity identified in tea alone but raises questions. For a better insight, the biological activities attributed to tea and to Kombucha are compared in Table 1. How tea composition is altered by the fermentation process has not been elucidated. Catechins are more and more recognized as responsible for the strong antioxidant activity, and the anti-cancer, anti-atherosclerosis, anti-inflammatory, and anti-diabetes properties of tea extracts. It is possible that these benefits attributed to Kombucha relate to the catechin content of tea itself. But catechin activity can also be modified by the chemical environment in the fermented beverage. For example, it has been reported that tocopherol and ascorbic acid exert strong synergistic effects on the antioxidant activity of tea catechins in a linoleic acid system (Hara et al., 1995f). Synergistic antimicrobial activity of ethanol, acetic acid, sodium chloride and essential oil has been demonstrated in vitro (Kurita & Koike, 1983). These kinds of interactions can be expected in Kombucha and merit more attention. It is likely that the effects reported for Kombucha such as stimulation of the immune system, digestion and liver function improvement or the enhancement of general metabolism may be the result of both attributes associated with tea and/or changes brought about by fermentation.

6. Kombucha: between a panacea and a dangerous drink

Although the consumption of Kombucha generally presents no adverse side effects, a few cases of health disorders have been reported. Upset stomach, some allergic reactions, particularly for those predisposed to acid sensitivities, and renal insufficiencies are usually improved by ceasing or lowering consumption (Frank, 1998). Four cases of possible toxic reactions and two cases of unexplained severe metabolic acidosis have been reported apparently related to Kombucha (Srinivasan, Smolinske & Greenbaum, 1997). One case of possible hepatotoxicity (Perron, Patterson & Yanofsky, 1995) and one case of skin disease (Sadjadi, 1998) have also been reported. Mechanisms of adverse effects have not been elucidated. When taking Kombucha, it is recommended to drink plenty of water to facilitate the elimination of toxins and to adjust consumption to any body reaction (Full Circle Press, 1998). Persons suffering from severe affliction should be aware of adverse side-effects brought about by Kombucha consumption.

Common sense should always be used to discard products with an abnormal odor or color and to adjust consumption to any body reactions (Full Circle Press).

When Kombucha is home cultivated, there is the possibility of contamination by potentially pathogenic bacteria and yeasts. For the non-initiate, seeing an ugly brown spongy mushroom floating in a cloudy brown liquid is not appetizing to look at and raises suspicions. Because fermentation is conducted in non-aseptic conditions and the culture is often propagated from one house to another, the potential for contamination is high (Mayser, Fromme, Leitzmann & Gründer, 1995). Contaminations are always possible but the zooglea protects itself against foreign microorganisms (Mayser et al., 1995). *Penicillium spp*. and *Candida albicans* have been identified in home cultivated tea fungus but no pathogenic bacteria have been found (Srinivasan et al., 1997). Contaminants have been suggested as being responsible for toxic reactions (Srinivasan et al., 1997). Kombucha must be prepared and stored in a glass container to avoid the leaching of toxic elements such as lead into the beverage from preparation or storage vessels (Phan, Estell, Duggin, Beer, Smith & Ferson, 1998; Srinivasan et al., 1997).

Kombucha is often claimed by enthusiastic supporters as a remedy for everything and a miracle elixir. Allegations are numerous and varied. The list includes the elimination of gray hair, the increase of sex drive, the improvement of eyesight, to the utilisation as a household cleaner, underarm deodorant or soothing foot soak (Ferguson & Estelle, 1998). Our review of the scientific literature revealed a lack of evidence to support many of these claims and raised doubts as to the validity of others. A more scientific approach is needed to separate real and indirect activities from unjustified claims. A first step is to identify all the constituents, those common with tea and others, produced during fermentation of Kombucha, especially those that may be potentially beneficial. More information about the mechanisms operating in the body is also needed to appreciate Kombucha's value and its limitations. Studies about health benefits of tea and studies about the action of organic acids on metabolism provide a useful starting point for understanding the possible activity of Kombucha. More research is needed to evaluate Kombucha, but there are new reasons to think that it may have a positive effect on human health. Today many food products are believed to be health promoters: yogurt, wine, cheese, fermented vegetables, kefir (Fuller, 1992). These products contain live bacteria or metabolites of bacteria produced during fermentation (Marteau & Rambaud, 1993). The impact these probiotic products have on metabolism and health is becoming more clear. Kombucha may indeed have many desirable effects on health. Findings about the beneficial effects of tea and fermented tea for health is meaningful because of the popularity of these beverages around the world.

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